NOAA SECTORAL APPLICATIONS RESEARCH PROGRAM (SARP)
PROJECT ANNUAL REPORT (DRAFT)

PROJECT TITLE

Climate-Informed Adaptive Management and Planning to Meet Urban Water Supply and Flood Mitigation Goals in the Delaware River Basin

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(Research team and full contact information)

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TIME PERIOD ADDRESSED BY REPORT *(e.g., August 2002-March 2003)*

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I. PRELIMINARY MATERIALS

A Project Abstract *(Limit to one page)*

The goal of this project is to incorporate climate and weather information into water resources management for the Delaware River Basin (DRB), in the context of the existing problems identified by DRB stakeholders. One problem is the lack of flexible operating rules that equitably meet the competing demands on the basin, which include federally mandated upstream diversions and instream flow rates for New York City water supply, flow and temperature requirements to meet conservation needs, and calls to use water supply reservoirs within the basin for flood mitigation. The other is the exclusion of climate variability and change considerations in the existing operating rules, which can have a substantial impact on the basin (e.g., recent floods and droughts), and can inform management decisions to better meet the aforementioned demands if known in advance.

We will work directly with collaborating DRB stakeholders to improve decision processes that will address these problems. To facilitate stakeholder engagement and implementation of results, our approach will be to build upon the management system that is already in place. By refining modeling and monitoring tools that are already used and trusted, the incorporation of climate and weather information will be more readily understood and therefore easier to accept. This is especially important given the probabilistic nature of climate forecasts and associated risks that must be communicated (e.g., if a climate forecast turns out to be inaccurate).

We propose to first develop a robust, probabilistic hydroclimatic forecasting and assessment capability for the DRB, then use it to design an effective, flexible and implementable adaptive Decision Support Tool for the DRB. These objectives will be achieved via a phased approach, in order to reconcile the short-term problem resolution needs within the DRB and the research application focus of the NOAA SARP element, with the research advancement needs that often arise when addressing complex, multi-user water resource management problems. The first phase will explicitly apply existing state-of-the-art climate-based forecasting techniques to the DRB, and refine the existing OASIS simulation system to explicitly incorporate this new information. The second phase consists of incremental improvements to the DST, through novel enhancements to hydroclimatic forecasting techniques and/or the DST, e.g. using Bayesian models and networks.

By providing an innovative yet familiar adaptive management system that can address competing demands by leveraging climate information, our results will benefit all DRB stakeholders, and by extension the societal interests represented by them. Our collaborating DRB stakeholders are amenable to this approach, and have expressed their written support for the proposed work.

B Objective of Research Project *(Limit to one paragraph)*

The goal of this project is to incorporate climate and weather information into water resources management for the Delaware River Basin. A climate-informed adaptive management and planning strategy addresses both the multi-stakeholder and climatic non-stationarity problems, since dynamic (i.e., based on current and future climate) operating rules provide greater flexibility with which to support multiple interests. Achieving our goal entails two distinct but integrated objectives. The first objective is the development of a robust, probabilistic hydroclimatic forecasting and assessment capability for the DRB region, at nested timescales from daily to multi-annual/decadal. Resulting climate-based hydrologic scenarios will serve as input for our second objective, which is the design of an effective, robust and implementable adaptive Decision Support Tool for the DRB.

C Approach (including methodological framework, models used, theory developed and tested, project monitoring and evaluation criteria) include a description of the key beneficiaries of the anticipated findings of this project (e.g., decision makers in a particular sector/level of government, researchers, private sector, science and resource management agencies) *(Limit to one page)*

Our methodological framework is divided into two phases, in order to reconcile the short-term problem resolution needs within the DRB and the research application focus of the NOAA SARP element, with the research advancement needs that often arise when addressing complex, multi-user water resource management problems. Phase I will apply current climate-based forecasting techniques to the DRB, and refine the existing OASIS simulation system to explicitly incorporate this new information. The focus is on application rather than enhancement, so as to introduce climate information into the current DRB system management in a timely, efficient and accessible manner. Phase II consists of a series of incremental improvements to methodologies applied in Phase I. System development plays a larger role, to overcome some of the limitations associated with current techniques. However, the incremental approach will allow us to maintain our focus on application and implementation of any new improvements. As the Decision Support Tool evolves it will retain its roots in the existing DRB management tools and thus remain accessible to all stakeholders.

We recognize at the outset that a stakeholder-driven approach relevant to specific questions is necessary to effectively introduce new climate information into the management of the DRB. Therefore, we have developed this proposal in the context of the existing water resources problems that are integral to the functioning of the DRB. Rather than seeking to educate decision makers about the role of climate information for some hypothetical application, or trying to engage a society-wide spectrum of users, we will work directly with DRB managers and stakeholders to improve decision processes, through the development of solutions to existing problems that utilize climate information.

To facilitate this direct and immediate engagement, our approach will be to build upon the management system that is already in place. By refining modeling tools that are already used and trusted by the various management entities, the incorporation of climate and weather information will be more readily understood and therefore easier to accept. This is especially important given the probabilistic nature of climate forecasts and associated risks that must be communicated (e.g., if a climate forecast turns out to be inaccurate). Furthermore, by starting within the current management framework, any limitations or weaknesses will be more apparent, so that more substantial modifications that may be required will be easier to implement. What will result is a viable, climate-informed, adaptively-managed decision support system for the DRB, which has its roots in an existing set of river basin simulation models that is frequently used and widely accepted by DRB managers and stakeholders.

To further expedite the application of our results into the actual decision-making process, we will focus initially on the upper-Delaware basin. Limiting the spatial domain in this way simplifies the physical system to be modeled considerably, so that climate-based impacts are easier to discern and interpret. Yet, the upper-Delaware includes the New York City water supply reservoirs, mandated streamflow criteria at Montague, NJ, and the fishery habitat that is of primary interest to conservation groups. Therefore many of the pressing problems facing the DRB can be effectively addressed by considering only its upper reaches.

D Description of any matching funds/activities used in this project *(Limit to one paragraph)*

None

II. ACCOMPLISHMENTS

A. Brief discussion of project timeline and tasks accomplished. Include a discussion of data collected, models developed or augmented, fieldwork undertaken, or analysis and/or evaluation undertaken, workshops held, training or other capacity building activities implemented. *(This can be submitted in bullet form – limit to two pages)*

During the prior reporting period, climate-informed reservoir release policy modifications were developed, using a seasonal streamflow forecast model derived from basic linear regression techniques. The modifications work within existing modeling and decision support tools used by stakeholders within the DRB, namely the OASIS model and the current operational rule curves. During the current reporting period, a framework for these modifications has been formalized, and a manuscript has been submitted to the Journal of the American Water Resources Association (AWRA). This work will also be orally presented at the upcoming AWRA 2009 Summer Specialty Conference - Adaptive Management of Water Resources II, June 29-July 1, 2009 in Snowbird, Utah.

The modest forecast skill developed during the prior reporting period hinders the effective implementation of our climate-informed reservoir release policy framework. Therefore the primary task during the current reporting period has been to improve upon the seasonal streamflow forecasts for the DRB region. First, temporal streamflow, precipitation, moisture flux and divergence patterns across all months have been evaluated to identify seasons with the greatest forecast potential, including the consideration of daily values and major events rather than simply monthly means. This fundamental review has helped us to develop improved geophysical intuition regarding the climatic phenomena that are likely to generate anomalous precipitation and hence streamflow over the DRB.

Second, nonlinear statistical forecasting techniques have been developed. The imposition of linearity for climate-streamflow relationships is a potentially limiting constraint that is borne of convenience and simplicity. Specifically, local regression has been applied to relate average streamflow during various two-month seasons to climatic predictors during the preceding two months. For individual candidate climate predictors, seasons and regions exhibiting a significant nonlinear relationship with lagged streamflow have been identified, and used to develop multiple local regression models for specified seasons. The forecast skill of these nonlinear models has been quantitatively compared to analogous linear forecast models.

B. Summary of findings, including their potential or actual implications for efforts to develop applications, methods, and science-based decision support capacity/systems and to foster sustainable resource management and vulnerability reduction. *(Limit to two pages)*

Analysis of streamflow, precipitation, moisture flux and divergence patterns indicate that streamflow in the study region is derived from a variety of climatic phenomena. The spring and autumn seasons exhibit the greatest potential for climate-based streamflow forecasting; spring flow is derived largely from the runoff of accumulated winter snowpack produced by winter storms, while autumn flow often results from tropical Atlantic cyclones that develop from warm summertime ocean waters. Streamflow in both seasons is also subject mid-latitude stationary and transient wave activity across North America (e.g., jet streams and storm tracks), which can originate as far away as the Pacific Ocean.

Based on these findings, non-linear statistical methods were used to search for meaningful relationships between large scale climatological predictors and streamflow during the September-October (SO), October-November (ON), and March-April (MA) two-month seasons. Using multivariate local regression, statistically significant relationships were identified with regional sea surface temperatures (SST) and 700mb wind velocities (for MA only) during the preceding two months.

For the SO and ON streamflow seasons, influential SST regions are located off the coast of West Africa, near the Gulf of Alaska and the tropical Eastern Pacific. SST anomalies in these three regions are indicative of tropical Atlantic cyclone activity, mid-latitude jet stream behavior and subtropical jet stream moisture, respectively. Each of these phenomena can bring anomalous moisture to the study region.

For the MA season, an influential SST region is located off the west coast of North America, which may be related to ENSO related stationary wave anomalies over North America. Influential 700mb wind regions of opposite sign are located over the Great Lakes and the Gulf of Mexico, which is indicative of changes in the location and strength of winter storm tracks over North America.

Using bivariate local regression, these physically-justifiable relationships were aggregated into streamflow forecast models for each season. Generally, the local regression models explained more variance than analogous linear regression models, however they tended to be less robust. Predictive simulations of a 10 year period whose observations were withheld from the model building generally showed improved predictions for the local regression model compared to the linear regression.

The identification of nonlinear lagged climate – streamflow relationships for the study region during specific seasons, and the demonstrated improvement of forecasts based on local regression rather than linear regression, increases the potential for climate – informed water supply management in the Delaware River Basin.

C. List of any reports, papers, publications or presentations arising from this project; please send any reprints of journal articles as they appear in the literature. Indicate whether a paper is formally reviewed and published. *(No text limit)*

A manuscript has been submitted to the Journal of the American Water Resources Association (AWRA), describing the climate-informed reservoir release policy modifications developed using a seasonal streamflow forecast model derived from basic linear regression techniques. It is provided as an attachment to this progress report.

Much of the analyses of seasonal streamflow predictability potential, development of nonlinear predictive relationships, and comparison of local vs. linear regression forecasts, are documented in the M.S. thesis of a graduate student funded by this project. It is provided as an attachment to this progress report, and a manuscript is currently being prepared for submission to a peer-reviewed publication.

D. Discussion of any significant deviations from proposed workplan (e.g., shift in priorities following consultation with program manager, delayed fieldwork due to late arrival of funds, obstacles encountered during the course of the project that have impacted outcome delivery). *(Limit to one paragraph)*

The streamflow forecasting skill achieved during the prior reporting period was modest and limited. Therefore a more fundamental analysis of streamflow prediction potential was performed during the current reporting period, which was not part of the original work plan. This has resulted in a clearer and more intuitive understanding of streamflow predictability in the study region, and will facilitate the improvement of forecasting and decision support capabilities as described in Phase II of the work plan.

Feedback from stakeholders continues to occur via informal discussions with individual stakeholders. Initially planned formal meetings involving all stakeholders were postponed in order to sufficiently develop streamflow forecasting capabilities. Formal meetings and presentations to stakeholders are currently being arranged, coinciding with manuscript submissions and conference presentations scheduled for summer 2009.

E. Where appropriate, describe the climate information products and forecasts considered in your project (both NOAA and non-NOAA); identify any specific feedback on the NOAA products that might be helpful for improvement. (bulleted response)

None.

III. GRAPHICS: PLEASE INCLUDE THE FOLLOWING GRAPHICS AS ATTACHMENTS TO YOUR REPORT

A. One Power point slide depicting the overall project framework/approach/results to date
B. If appropriate, additional graphic(s) or presentation(s) depicting any key research results thus far
C. Photographs (if easy to obtain) from fieldwork to depict study information (if applicable).

IV. WEBSITE ADDRESS FOR FURTHER INFORMATION (IF APPLICABLE)

V. ADDITIONAL RELEVANT INFORMATION NOT COVERED UNDER THE ABOVE CATEGORIES.